

Lost carbon emissions: the role of non-manufacturing “other industries” and refining in industrial energy use and carbon emissions in IEA countries[☆]

Scott Murtishaw^a, Lee Schipper^{b,*}, Fridtjof Unander^b,
Sohbet Karbuz^b, Marta Khrushch^{1,a}

^aInternational Energy Studies, Energy Analysis Department, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

^bInternational Energy Agency, Energy Technology Policy Division, 9 rue de la Federation, 75739 Paris Cedex 15, France

Received 31 May 2000

Abstract

We present a review of trends in energy use and output in branches of industry not often studied in detail: petroleum refining and what we call the other industries — agriculture, mining, and construction. From a sample of IEA countries we analyze eight with the most complete data from the early 1970s to the mid-1990s. We carry out a decomposition analysis of changes in energy use and carbon emissions in the “other industries” sector. We also review briefly the impact of including refining in the evolution of manufacturing energy use, usually studied without refining. Despite many data problems, we present our results as a way of enticing others to study these important “lost” sectors more carefully. We have five basic findings. First, “other industries” tends to be a minor consumer of energy in many countries, but in some, particularly Denmark, the US, and Australia, mining or agriculture can be a major sector too large to be overlooked. Second, refining is an extremely energy intensive industry which despite a relatively low share of value added consumes as much as 20% of final energy use in manufacturing. Third, as a result of a slower decline in the carbon-intensity of these industries vis-à-vis the manufacturing industries, their share of industrial emissions has been rising. Fourth, for other industries variation in per capita output plays a relatively small role in differentiating per capita carbon emissions compared to the impact of subsectoral energy intensities. Finally, including this energy in CO₂ calculations has little impact on overall trends, but does change the magnitude of emissions in most countries significantly. Clearly, these industries provide important opportunities for searching for carbon emissions reductions. © 2000 Elsevier Science Ltd. All rights reserved.

1. Introduction

Analyzing important sectors of economies where energy-related carbon emissions occur is an important task on the road from Kyoto. Because of statistical difficulties

and definitional problems, key parts of productive sectors of economies are often overlooked in analyses of energy use. These sectors consist of agriculture (including hunting, fishing, and forestry), mining (including the extraction of mineral resources), and construction, which together we call “other industries”. This aggregation of other industries differs from the International Energy Agency (IEA) methodology in which construction and mining of non-fuel resources are placed in the industry sector and energy resource mining (including uranium) is classified in the energy transformation sector. IEA also places agriculture into “other sectors” with residential and commercial. Additionally, we examine the refining industry, which is often one of the largest energy consuming industries in a country’s manufacturing mix. However, in many countries it is excluded from total final consumption in national energy balances and classified as part of the energy transformation sector. When proper

[☆]This work was carried out jointly at the International Energy Agency and the Lawrence Berkeley National Laboratory. Scott Murtishaw was supported by the Shell Int’l Petroleum Company, under a grant to the University of California Berkeley, Goldman School of Public Policy, by Exxon Co. Int’l, under a gift to the Lawrence Berkeley National Laboratory, and by the US Environmental Protection Agency, under contract DE-AC03-76SF00098 to the Lawrence Berkeley National Laboratory. Opinions are those of the authors and not of the sponsoring or hosting institutions.

¹ Presently at the London School of Business.

* Corresponding author. Tel.: + 33-1-4057-6714; fax: + 33-1-4057-6749.

E-mail address: lee.schipper@iea.org, ljschipper@lbl.gov (L. Schipper).

Nomenclature

| | | | |
|------------------------------|---|---|--|
| E_T | total energy consumption in industry in year T | $(1 + \Delta I_{struc})_{0,T}$ | index component of estimate of the change in aggregate energy intensity due to a change in the subsectoral activity mix between year 0 and year T |
| $E_{j,T}$ | energy consumption in industrial sector j in year T | $(1 + \Delta I_{int})_{0,T}$ | index component of estimate of the change in aggregate energy intensity due to the changes in subsectoral energy intensities between year 0 and year T |
| Y_T | total industrial production in year T | $D_{0,T}$ | residual |
| $Y_{j,T}$ | production of sector j in year T | <i>Source:</i> Greening et al. (1996), Liu et al. (1992). | |
| $S_{j,T}$ | production share of sector j in year T given by $Y_{j,T}/Y_T$ | | |
| I_T | energy-output ratio in year T given by E_T/Y_T | | |
| $I_{j,T}$ | energy intensity for sector j in year T given by $E_{j,T}/Y_{j,T}$ | | |
| $(1 + \Delta I_{tot})_{0,T}$ | index of actual change in aggregate energy intensity between year 0 and year T , where year 0 is the first year of a period | | |

accounting of these sectors is made, they generally represent about 10% of total final energy use in industrialized countries. Despite the data problems, the rudimentary analysis offered here demonstrates that ignoring these sectors leaves a significant hole in the analysis of the patterns of energy use and carbon emissions of IEA countries.

In this paper for the first time we present a decomposition analysis of changes in delivered (final) energy use and carbon emissions in the other industries sector.² Recent analyses of the manufacturing sector is found in Unander et al. (2000) and Schipper et al. (2000). We begin by describing our data sources and discussing problems with data for refining and non-manufacturing industries in Section 2. The decomposition and mine-yours methods are presented in Section 3.³ Section 4 offers a brief overview of the broad trends in the shares of total national energy use and carbon emissions represented by these industries. Detailed decomposition and mine-yours results for refining and non-manufacturing industries are given in Sections 5 and 6. A comparison of these industries to the manufacturing industries is presented in Section 7. In Section 8, we contrast emissions trends before and after 1990 to assess the progress in reducing emissions from the Kyoto benchmark year. We conclude in Sections 9 and 10 with discussion of data uncertainties, the role of these industries in developing countries, and a review of our findings.

2. Data sources and reliability

We have not included the three other industries in our previous analyses of manufacturing because in many countries their data are often less consistent than manu-

facturing industries' data. In addition to missing data for the 1970s, data reliability remains a problem even for recent years. In many IEA member countries, the "other industries" sectors are scattered through manufacturing or even "other consumers", a classification normally associated with the service sector.

Our analysis of other industries relies on an energy consumption database at Lawrence Berkeley National Laboratory, which uses figures reported in national accounts publications. We base this study on a sample of eight IEA member countries consisting of Australia, Denmark, Finland, Italy, Japan, Sweden, the United Kingdom (UK) and the United States (US). This group will be referred to in the paper as the IEA-8. Other countries that were included in our previous work on manufacturing have not been included in this study due to unreliable or missing data for the industries considered in this study. Since many of our analyses examine trends back to 1973 to compare energy intensities before and after the oil price shock, we could not include Norway, the Netherlands, and Canada, for which we lack data for the early 1970s. West Germany⁴ is excluded from the study due to data problems. Although Swedish data start officially in 1982, they have been estimated back to 1970 as published in a previous study (Schipper and Price, 1994). Danish data are missing for 1973 and 1974, but we have estimated the figures for these years based on the data for 1972 and 1975. Data for UK mining electricity consumption have been estimated for the years following 1988 since subsequent to that year they were aggregated with the coke production industry. UK mining fuel consumption is included in non-metallic minerals for recent years and also had to be estimated from earlier years.⁵

² Delivered energy means the same as final or site energy. It does not include the energy lost in the transformation and distribution of electricity and district heat. In this paper use of the term "energy" refers to delivered energy unless otherwise noted.

³ See Schipper et al. (2000) for a more detailed discussion of the methodology.

⁴ The previous studies did not include energy consumption in the territory of the former East Germany in order to maintain comparability of pre- and post-1990 figures.

⁵ To estimate the electricity consumption from 1988 to 1994 we projected a trend line of the electricity intensity (defined as electricity use per value added) from the previous 10 years and multiplied the projected intensities by the actual value added figures.

Petroleum refining has been excluded from our previous work for similar reasons. For example, France is not included because the value added data for refining could not be disaggregated from figures containing value added from petrochemicals. For some countries, the energy consumed by refineries is included in total manufacturing (Canada, for example), while for others (e.g., the Netherlands, Norway, and Germany), only the relatively small component of purchased energy is included. Many countries (and the IEA) consider the refining sector to be a transformation sector, so crude oil used in the refining process is counted as a loss in energy transformation. An adequate and correct comparison of total manufacturing energy use is only possible if the same industries are covered. For example, if petroleum refining were excluded from the 1994 US Manufacturing Energy Consumption Survey (MECS), the resulting manufacturing energy consumption figures would be 19% lower.

3. Methodology

We attribute changes in the total energy consumption in refining to two factors: the level of economic activity and the energy intensity of production. Activity is measured in terms of dollar output⁶ and intensity is calculated as the amount of energy required to produce a dollar's worth of output measured in megajoules (MJ). For other industries the energy intensity effect is calculated by subsector and a structural component that measures the impact of changes in the output shares of the sector's industries is included. For example, the structure index would quantify the increase in other industries' aggregate intensity resulting from a relative shift in value added from construction to mining, which is a more energy-intensive industry. We use the Adaptive Weighting Divisia (AWD) decomposition method to determine the relative importance of each of the above factors on changes in energy use over time (Liu *et al.*, 1992; Greening *et al.*, 1996, 1997). This method calculates the annual percentage change in actual energy use attributable to economic activity, changes in subsectoral energy intensities, and structure. Since refining, as a single industry, does not have an easily measured structural component, an AWD decomposition for refining has not been performed.⁷ However, our decompositions of manufacturing have been calculated both with and without refining, and differences in the results are discussed below.

⁶ All currency figures used in this analysis are 1990 real US dollars adjusted for purchasing power parity.

⁷ Strictly speaking, the mix of output products would provide a valuable structural indicator for refining, but obtaining good estimates of energy use per unit of output for each refinery product is difficult. Nevertheless, we give some indications of these changes below.

For carbon emissions we decompose actual carbon emissions into the product of activity and aggregate carbon intensity. Similar to the energy use decomposition, we use the AWD method to measure the impact of changes in structure and subsectoral energy intensities on the aggregate carbon intensity. However, since fuels release different amounts of carbon per unit of energy, changes in the mix of fuels used also affect carbon intensity. Two additional terms measure the effects of changing fuel shares because fuel switching may occur at either the end-user level or at the utility level. To estimate the carbon released from each fuel type we use the simplified carbon coefficients for fossil fuels in accordance with Intergovernmental Panel on Climate Change (IPCC) methodology⁸ (IPCC, 1996). For each country carbon coefficients have been calculated for purchased electricity and district heat based on the fuel inputs in each country's generation mix and the ratio of energy consumed by utilities to energy delivered (which we refer to as the primary coefficient). Thus, changes in aggregate carbon intensity are the product of changes in structural effects, subsectoral energy intensities, end-user fuel switching (fuel mix), and utility fuel switching (utility mix). A more detailed explanation of the AWD method is given in the appendix.

4. Role of "other industries" and refining in total national energy consumption and carbon emissions

It is important to account for energy consumption by other industries and refining because together they constitute a sizeable share of national energy use. These industries together represented 10% of IEA-8 delivered energy use in 1994, a share that has been quite stable for the IEA-8 as a whole over our study period from 1973 to 1994. However, in some countries the share of these industries has changed markedly. Fig. 1 shows that other industries in Sweden and Australia have undergone major transformations. In Sweden the growth in the share of these industries was driven by refining energy consumption, which grew at an annual average of over 4% during this time. Other industries' energy consumption in Australia grew consistently during this time relative to other sectors. The decline in energy share for the IEA-8 to 1986 resulted largely from diminishing energy intensity in refining to the mid-1980s. The subsequent upturn is mostly the result of output growth in refining and mining.

Including refining and other industries has little effect on the trends in total national energy use or carbon

⁸ The IPCC carbon factors are 21.1 ktC/PJ for petroleum products, 15.3 ktC/PJ for natural gas, and 25.8 ktC/PJ for coal.

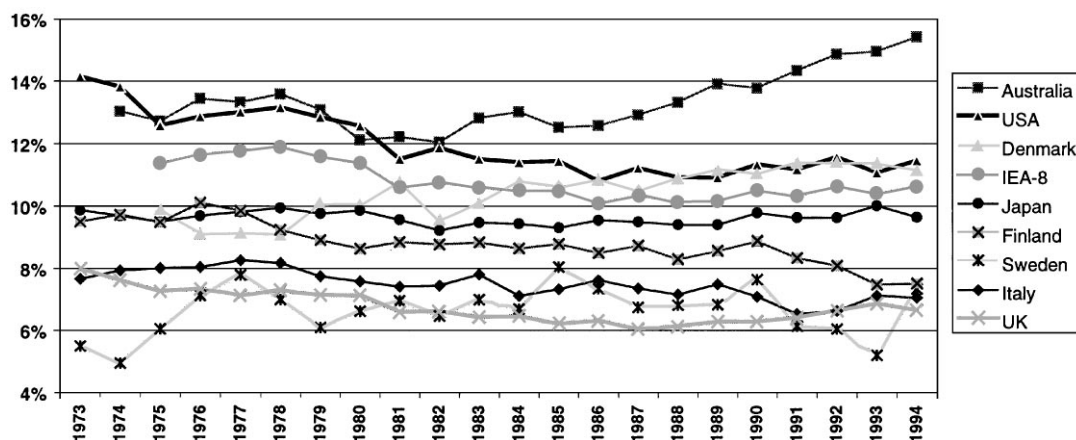


Fig. 1. Refining and other industries share of total national energy consumption.

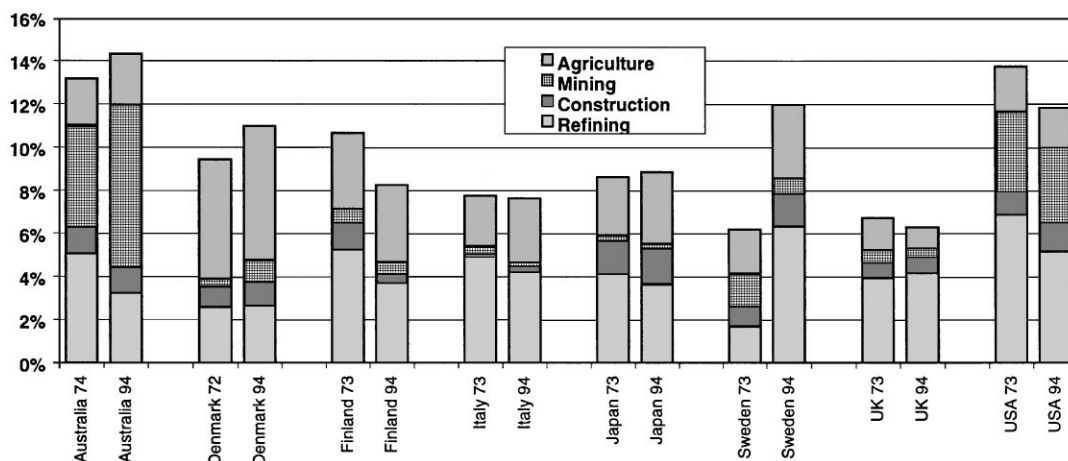


Fig. 2. Refining and other industries' share of total CO₂ emissions from energy use: 1973–1994.

emissions for most countries. Sweden experienced the largest change in the growth rate of actual emissions with an increase of just 0.3% per year when refining and other industries are included. In general, including these industries causes total national carbon emissions and carbon intensity to decline less rapidly.

While including refining and other industries may not appreciably affect national emissions trends, they are important contributors to national emissions, constituting 10% or more of total emissions in four of the IEA-8 countries. Fig. 2 shows how the shares of emissions from these two sources have changed over time. For the IEA-8 as a whole the share has been quite stable, falling from 12% in 1973 to 11% in 1994. Sweden experienced the largest shift in the relative emissions share of these industries. Refining emissions matched the growth of energy demand at an average annual rate of 4% while emissions from the other branches of manufacturing and the other sectors except for travel and freight

declined.⁹ The greatest decline in emissions share occurred in Finland, where emissions from both refining and other industries fell while those from the residential, travel, and freight sectors increased.

5. Refining

In 1994 petroleum refining contributed approximately \$28.5 billion to IEA-8 economies, a 15% increase since 1973 in real terms. Still, this amounts to less than one-half percent of the total IEA-8 GDP. Countries

⁹ We divide national energy consumption and carbon emissions into six sectors: residential, services/commercial, manufacturing, other industries, travel, and freight. Our calculations in these sectors include indirect carbon emissions, i.e., carbon emissions from purchased heat and electricity.

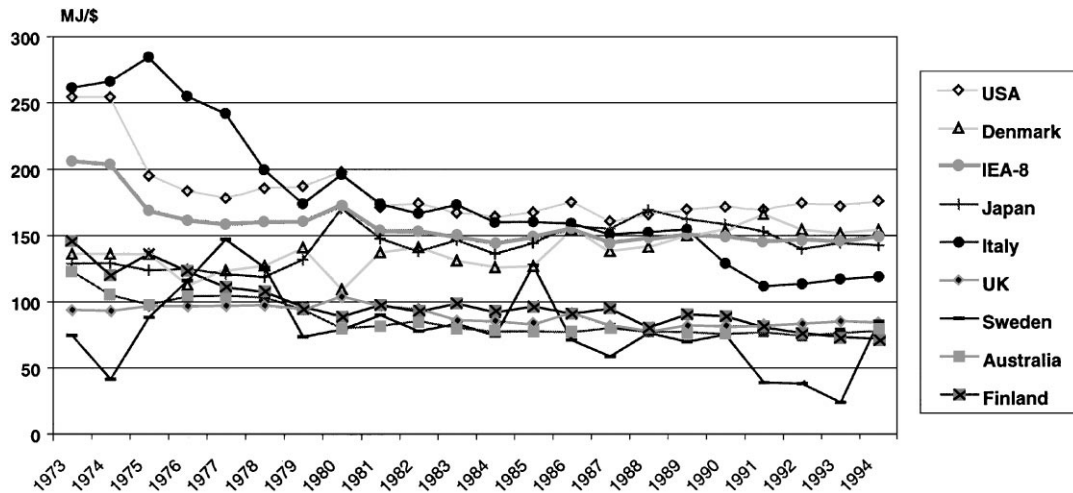


Fig. 3. Refining energy intensities, 1973–1994.

experiencing strong growth in refining value added during this period include Australia, Finland, Italy, and Sweden. In Sweden the industry has declined since 1990, while the output from Japan, Finland, and Denmark surged in the early 1990s.

5.1. Energy consumption trends

Total IEA-8 energy use fell steadily from 1973 to 1985 at an average annual rate of 0.7%. However, since 1985, refining energy use has been increasing steadily. Refining accounted for 15% or more of 1994 manufacturing energy consumption in three IEA-8 countries and an average of 12% overall. Refining energy use as a share of manufacturing energy consumption has grown in the early 1990s for all countries but Finland and the US.

Fig. 3 depicts the evolution of energy intensities among the IEA-8 over our study period. Aggregate IEA-8 energy intensity declined at about 1.5% per year over the study period, although a strong downward trend from 1973 to 1984 reversed sharply in 1985. US energy intensity fell drastically from 1974 to 1975, but it is possible that this is due mostly to a change in reporting methodology. If the 1973 and 1974 energy use by US refineries was in fact much closer to the 1975 level, then the IEA-8 energy intensity would fall by only 0.7% per year. Refining energy intensity has declined most in Italy and Finland, at greater than 3% per year.

In order to examine the influence of price changes on our analysis of energy intensity we recalculated the intensities based on physical output.¹⁰ Worrell *et al.* (1997)

demonstrated that energy intensity indicators based on physical output for the iron and steel industry proved to be more accurate and more stable over time. A comparison of intensity trends defined in physical terms does not in fact radically alter our findings. The results of these calculations are shown in Fig. 4. The IEA-8 intensities given by both methods fall from the early 1970s to the mid-1980s and then rise to 1989/1990. While the trends have moved in the same direction, they have been more pronounced when defined in economic terms. The average annual rate of growth for value added was only slightly higher than net physical output. Thus, there is only a small difference in the long-term rates of change for both indicator methodologies (see Table 1).

These results are not necessarily counterintuitive. As the price of oil rises, the cost of refinery input increases along with the prices of the outputs. The net value of refinery output may therefore not depend heavily on crude prices. The physical indicators will be more accurate and stable over time only if the ratio of the value added to the net physical output changes significantly. Analysis of our data does not indicate that on average this has been the case for the IEA-8. Since this ratio has not changed drastically for most of the IEA-8 countries, we find that using the physical indicators does not yield results much different from those derived from economic indicators. In order to check the hypothesis that physical indicators might be subject to less volatility than economic indicators, we compared the standard errors of the data points around the regression line of energy intensities over time. The results are quite mixed, as Table 1 shows. At the IEA-8 aggregate level, there is little difference between the two.

The choice of indicator does have a strong impact on the ranking of the countries and on the intensity trends for certain countries (Figs. 3 and 4). The difference is

¹⁰ Output data are net refinery outputs (gross production–refinery fuel) taken from an oil production database at the International Energy Studies group, Lawrence Berkeley National Laboratory.

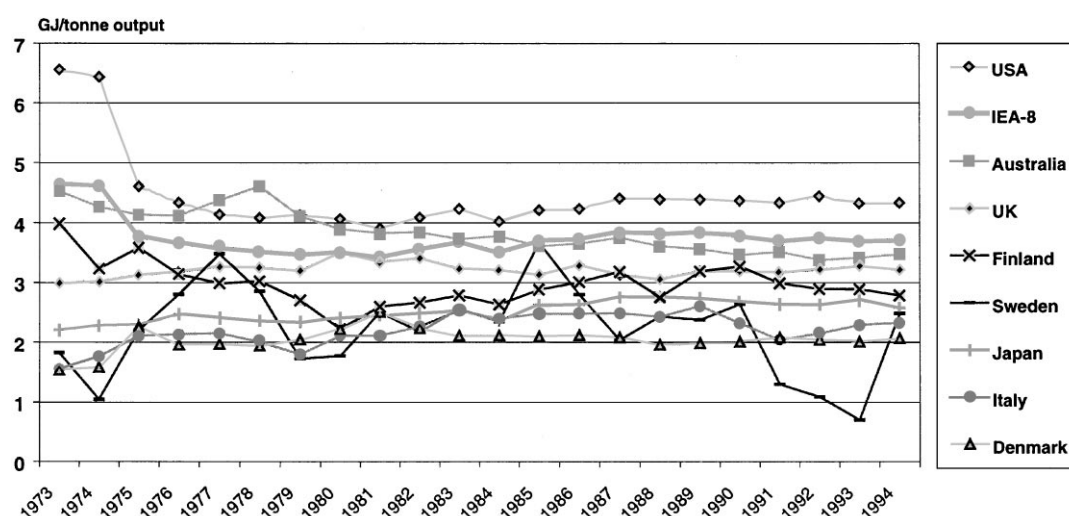


Fig. 4. Refining physical energy intensities, 1973–1994.

Table 1
Average annual rates of growth of economic and physical indicators of energy intensity

| | Economic indicator | | | | | Physical indicator | | | | |
|-----------|--------------------|-----------|-----------|-----------|-----------------------|--------------------|-----------|-----------|-----------|----------|
| | 73–84 (%) | 84–90 (%) | 90–94 (%) | 73–94 (%) | S.E. ^a (%) | 73–84 (%) | 84–90 (%) | 90–94 (%) | 73–94 (%) | S.E. (%) |
| Australia | –4.2 | –0.4 | 0.7 | –2.2 | 8.3 | –1.7 | –1.4 | 0.1 | –1.3 | 4.0 |
| Denmark | –0.7 | 3.3 | 0.1 | 0.7 | 7.7 | 2.9 | –0.8 | 0.7 | 1.4 | 9.7 |
| Finland | –4.2 | –0.6 | –5.3 | –3.4 | 9.2 | –3.8 | 3.6 | –4.0 | –1.7 | 12.0 |
| Italy | –4.5 | –3.6 | –2.1 | –3.8 | 10.5 | 4.0 | –0.5 | 0.1 | 1.9 | 9.9 |
| Japan | 0.5 | 2.5 | –2.7 | 0.5 | 8.7 | 0.6 | 2.1 | –1.0 | 0.7 | 3.6 |
| Sweden | –0.1 | 0.2 | 3.1 | 0.6 | 34.9 | 2.3 | 2.0 | –1.5 | 1.5 | 33.9 |
| UK | –0.9 | –0.7 | 0.7 | –0.5 | 5.2 | 0.7 | –0.1 | 0.2 | 0.4 | 3.8 |
| USA | –4.0 | 0.7 | 0.7 | –1.8 | 10.6 | –4.4 | 1.4 | –0.2 | –2.0 | 14.2 |
| IEA-8 | –3.2 | 0.5 | 0.0 | –1.5 | 7.3 | –2.6 | 1.3 | –0.5 | –1.1 | 8.1 |

^a These values equal the normalized standard errors (with time as the independent variable) of the energy intensity time series data for each country.

particularly stark for Italy, but we are unsure about the reason for the discrepancy between the changes in reported output and value added. Measuring energy intensity using aggregate physical output may also be problematic, as the composition of refinery output changes over time (see Fig. 5). The mix of outputs has shifted to higher end products that require more intensive refining than heavier products. Refining gasoline, for example, requires more than twice as much energy per unit as refining kerosene or fuel oil (Worrell *et al.*, 1994). Since 1973 the share of lighter products (e.g., gasoline, diesel, and naphtha) has increased from 55 to 62% (IEA, 1998), which would tend to increase aggregate energy intensity. Thus, the energy intensities of specific products have fallen more rapidly than these aggregate physical indicators suggest. However, given that lighter products generally have a higher value added per unit of physical

output than heavier products, the influence of the product mix is at least partially controlled for by the economic indicator.

Although we have not performed an output-adjusted analysis of energy intensity, we estimate the effect of changing product mix on aggregate physical intensity using the best-practice specific energy consumption figures reported by Worrell *et al.* (1994) to find a weighted average intensity of the output mixes of 1973 and 1994. The gross production in tons of each product is multiplied by the specific energy consumption for that product and the resulting energy use figures for each product are summed. The total energy consumption is then divided by the total production of all products. This calculation suggests that changing output mix has increased energy intensity in the IEA-8 by approximately 5%.

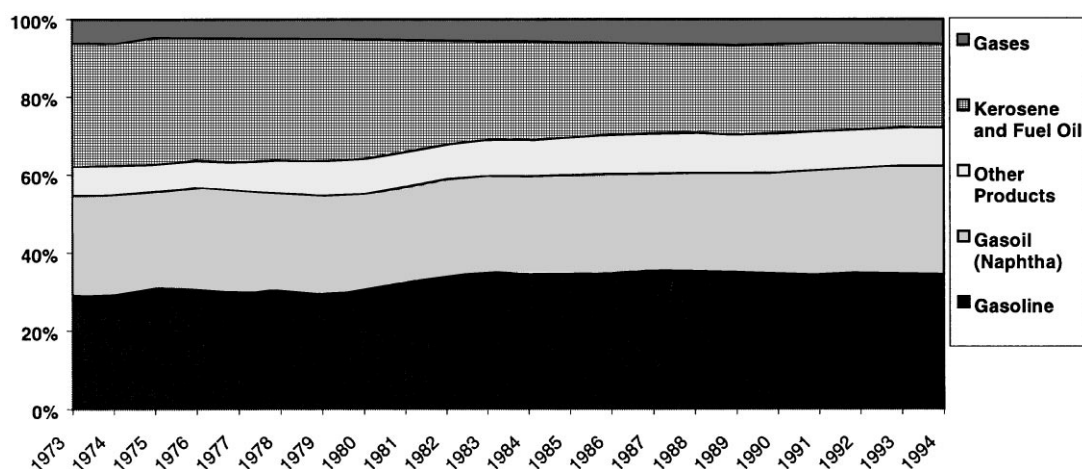


Fig. 5. Shares of gross refinery output, measured in tonnes: 1973–1994.

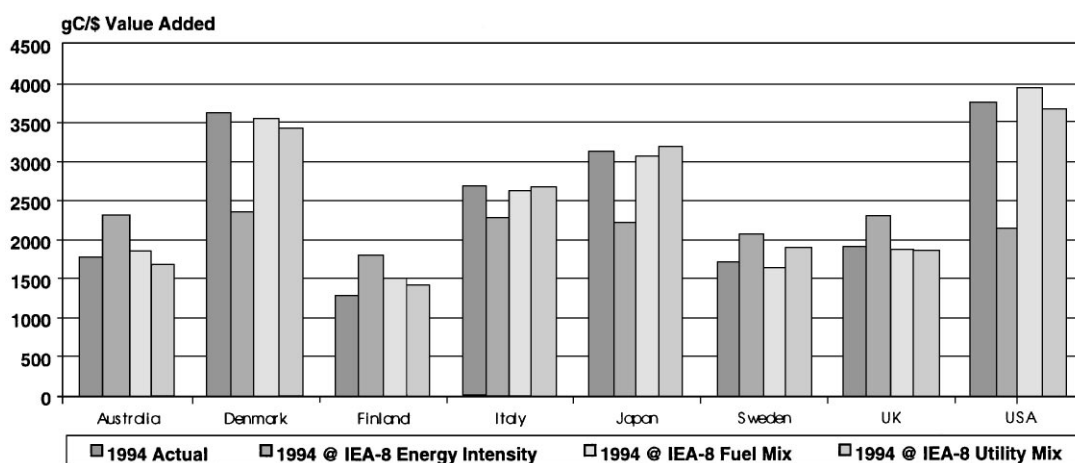


Fig. 6. 1994 refining carbon intensities: actual and intensity, fuel mix, and utility mix effects.

5.2. Carbon emissions results

Including refining in manufacturing does not significantly alter the carbon emissions decomposition results for most countries. The difference in the average annual rates of growth of either actual emissions or any of the decomposition terms is 0.3% or less. The major exception to this rule is Sweden for which the inclusion of refining leads to an increase in the annual growth rate of emissions of almost 1%. However, the reported energy consumption from Sweden is so erratic that it is dubious to draw any firm conclusions based on these results. Generally, including refining does slightly increase the value of the energy intensity decomposition term, indicating that energy intensity has fallen less rapidly in refining than in other manufacturing industries.

Fig. 6 depicts the relative importance of energy intensity, fuel mix, and utility mix in determining the differences in carbon intensity among the IEA-8 countries' refining industries. In this "mine-yours" analysis, we substitute the IEA-8 unweighted average value¹¹ for energy intensity for each country's own energy intensity while holding the fuel mix and utility mix constant. In other words, for the US we calculate the hypothetical carbon intensity of US petroleum refineries as if they had

¹¹ Unweighted averages are used due to the overwhelming influence of the US in the sample. In 1994 the US accounted for 43% of IEA-8 refining value added and 68% of IEA-8 emissions. Thus, characteristics of the US industry strongly influence aggregate results. For example, the weighted average 1994 IEA-8 carbon intensity is 2400 gC/\$. The average when the US is excluded drops to 1380 gC/\$.

the same energy intensity as the average of all the sample countries. We then do a similar calculation for fuel mix. For the fuel mix substitution we calculate the carbon intensity based on the average share of fuels. For example, we determine what the US carbon intensity would be if it used the same percentages of oil, gas, coal and electricity to meet its energy demand as the average shares for all countries. In these calculations each country's own carbon coefficient for electricity is used. For the utility mix substitution we simply subtract the emissions due to electricity for each country and then multiply that country's electricity consumption by the average carbon factor for electricity and add this back to total emissions from fuels. To gauge the relative impact of each term, an average deviation for each is calculated by taking the mean of the absolute percentage changes from actual carbon intensity due to that term.

One observation that is immediately apparent from the graph is the large variation in carbon intensity in these countries. The US and Denmark are more than 1.5 times more carbon intensive than the average of the other IEA-8 countries. The mine-yours analysis reveals that differences in energy intensity play a much larger role in the variance in carbon intensities than fuel mix effects do. Substitution of the energy intensity term results in an average absolute change of 29% from actual carbon intensity. Emissions from Denmark, Japan, and the US would have been much lower if their energy intensities had been closer to the average. If the US had the average intensity, *total* IEA-8 refining emissions would have been almost 30% less than the actual. This suggests that efforts to reduce energy intensity among large emitters like Japan and the US could make important contributions in reducing carbon emissions from this industry.

Fuel shares are relatively homogenous in this industry so differences in fuel mix do not play a large role in differentiating carbon intensity for most countries. In five of the IEA-8 countries oil provides more than 90% of the delivered energy with electricity accounting for virtually all of the rest. There are some interesting exceptions. Fuel share substitution increases US carbon intensity by 7%. This is due to the 23% of delivered energy from natural gas, a share that has been relatively stable since the early 1970s. The only country using a larger share of natural gas in 1994 was Finland.

Utility mix substitution also has little effect. Like fuel mix, it results in a mean absolute deviation from actual carbon intensity of less than 5%. This is largely because electricity constitutes just 5% of IEA-8 delivered energy consumption. Thus, variation in the carbon coefficients for electricity only affects a small portion of the total emissions for most countries. The countries where this effect is most pronounced are Finland and Sweden, where carbon intensity would have increased 9 and 8%, respectively, at the average utility mix.

6. Other industries

In 1994 other industries consumed 5.2 exajoules of delivered energy in the IEA-8, which is equivalent to 6% of all delivered energy consumed of total final demand in these countries. This proportion has changed very little over the study period. The US represents an extremely large share of IEA-8 energy use in this sector, having consumed 71% of the 1994 total, a share that has actually fallen since 1973.

Other industries contributed over a trillion dollars to the IEA-8 economies in 1994. As a share of GDP, other industries declined from 13 to 10% from 1973 to 1983, after which the share has held through 1994. From 1973 to 1994 other industries' share of GDP grew only in the UK although GDP share increased in none of the IEA-8 countries in the early 1990s. Among the national economies, other industries were most important to Australia where their 1994 share of GDP was 14%. The US, at 8%, had the lowest share.

Compared to manufacturing and services, economic growth in this sector has been relatively stagnant. From 1973 to 1994 IEA-8 other industries' per capita output grew only 9%. In contrast per capita services output grew 65%, and per capita manufacturing grew 31%. The only countries to experience significant per capita growth in other industries were Australia (32%), Japan (23%), and the UK (40%). Growth in other industries in the IEA-8 was, on average, led by agriculture, which grew at more than twice the rate of construction and mining. However, the three countries with strong growth in the sector were exceptions. In Australia and the UK most of the growth in value added came from mining. In Japan the construction industry experienced robust growth while value added from agriculture and mining both declined in real terms.

Aggregate delivered energy intensities for other industries vary considerably among the IEA-8 countries. To give a more detailed explanation of the variation in aggregate energy intensities, Table 2 provides the subsectoral energy intensities and the respective shares of value added for each industry in the sector. This table helps to illustrate how sectoral energy intensities are a function of both the subsectoral energy intensities and the GDP shares of each subsector. The total sectoral energy intensity for each country is equal to the average of the subsectoral energy intensities weighted by the GDP shares.

The figures in Table 2 indicate that there are notable differences in energy intensity between the branches of this sector. For example, construction is far less energy intensive than agriculture, which is less than half as energy intensive as mining. However, energy intensity also varies considerably within each industry. In the UK where mining energy intensity is far below the IEA-8 average, the extraction of liquid hydrocarbons

Table 2
1994 Subsectoral energy intensities and GDP shares

| Country | Energy intensity MJ/\$ value added | | | | Subsectoral GDP shares | | |
|-----------|------------------------------------|-------------|--------|--------------|------------------------|------------|------------------|
| | Total | Agriculture | Mining | Construction | Agriculture (%) | Mining (%) | Construction (%) |
| Australia | 7.6 | 5.5 | 17.3 | 2.4 | 28 | 29 | 43 |
| Denmark | 6.0 | 11.5 | 5.0 | 1.6 | 40 | 14 | 46 |
| Finland | 4.3 | 6.9 | 16.7 | 0.7 | 50 | 3 | 47 |
| Italy | 1.7 | 4.2 | 1.3 | 0.2 | 37 | 6 | 56 |
| Japan | 2.6 | 9.3 | 7.0 | 1.0 | 18 | 2 | 81 |
| Sweden | 4.5 | 8.4 | 26.3 | 1.6 | 28 | 4 | 68 |
| UK | 1.4 | 4.0 | 0.6 | 0.9 | 16 | 26 | 57 |
| USA | 7.6 | 7.3 | 19.4 | 2.8 | 27 | 22 | 51 |
| IEA-8 | 5.1 | 7.1 | 15.4 | 1.7 | 25 | 15 | 61 |

predominates in the industry. We have not analyzed energy and energy intensity disaggregated down to the level of individual mining products, but it would appear that oil and gas extraction are far less energy intensive than hardrock mining.

6.1. Energy consumption trends

Other industries' delivered energy use in the IEA-8 decreased from 1973 to 1985 but has risen steadily since. However, by 1994 other industries' delivered energy consumption had increased only slightly above 1973 levels. Delivered energy use in other sectors increased from 12 to 58%, except for manufacturing, where energy use fell by 9%. In five IEA-8 countries, the share of other industries energy demand increased while in four it decreased. Australia had by far the largest increase in total other industries energy consumption, with delivered energy in 1994 greater than 2.5 times 1973 consumption, but delivered energy actually declined in Finland, Sweden, the UK, and the US.

Among the IEA-8 aggregate delivered energy intensity for the other industries sector declined by 17% from 1973 to 1994, in contrast to the manufacturing sector, whose energy intensity fell 43% during this time. However, half of the IEA-8 countries actually experienced increases in aggregate energy intensity, particularly in Australia (49%) and Italy (32%) and to a much lesser extent in Denmark and Japan. Average IEA-8 construction energy intensity remained virtually unchanged from 1973 to 1994, while agriculture and mining energy intensity declined by 22 and 27%, respectively.

While most of the analysis presented here focuses on trends in delivered energy, we are also concerned with the consumption of total (primary) energy. Since energy is lost both in the transformation of fuels to electricity and in the transmission and distribution of electricity,¹² utili-

ties require considerably more energy input than they deliver. Other factors being constant, a shift in fuel mix toward greater electricity consumption will lead to greater total energy consumption. Therefore, in countries where the share of electricity has significantly changed over time, trends in energy intensity may differ appreciably depending on whether intensity is defined in terms of delivered or primary energy.

The ratio of input energy to delivered energy (i.e. the primary coefficient) may also change over time. These changes may be due to several factors, such as improvements in energy transformation technology or in the transmission and distribution system. Fuel types in the utility mix also affect the primary coefficient since little energy is considered lost for electricity from hydro or wind sources. Thus, a switch to these energy sources would tend to lower the primary coefficient.

Table 3 summarizes the changes in electricity fuel share and in the primary coefficients from 1973 to 1994. For some IEA-8 countries the trends in primary intensity differ sharply from delivered intensity. In Finland and Sweden, where both the share of electricity and the primary coefficients have increased, primary intensity increased despite the slight reductions in delivered energy intensity. In the UK a declining primary coefficient offset the slight increase in electricity share, resulting in no discrepancy between the changes in primary and delivered intensities while Australia's declining primary coefficient brought down primary intensity even though the electricity share did not change.

The striking contrasts in the intensity results for Denmark, Finland, Italy, Sweden, and the US underscore the need to consider the effects of electrification. Improvements in end-use energy efficiency may only partly offset the impact of a rising share of electricity on primary energy. For countries with high proportions of fossil fuels in their electricity generation mix, the trend toward greater electrification in the other industries, manufacturing, residential, and commercial sectors is worrisome both for the consequences on total energy consumption and carbon emissions. On the other hand, Schurr (1982)

¹² The use of district heat in this sector is negligible (less than 0.1% in 1994) so we limit the discussion to electricity.

Table 3
Effect of changing shares of electricity in other industries on primary intensity

| Country | Share of electricity in total delivered energy | | Electricity primary coefficients | | Change in energy intensity 1973–1994 | |
|-----------|--|----------|----------------------------------|------|--------------------------------------|-------------|
| | 1973 (%) | 1994 (%) | 1973 | 1994 | Delivered (%) | Primary (%) |
| Australia | 15 | 15 | 3.54 | 3.08 | 49 | 41 |
| Denmark | 6 | 16 | 2.96 | 2.43 | 4 | 22 |
| Finland | 10 | 15 | 1.46 | 2.35 | – 4 | 10 |
| Italy | 11 | 16 | 2.62 | 2.59 | 32 | 41 |
| Japan | 5 | 4 | 2.51 | 2.64 | 6 | 5 |
| Sweden | 23 | 29 | 1.22 | 2.26 | – 6 | 22 |
| UK | 13 | 16 | 3.57 | 3.06 | – 56 | – 56 |
| USA | 8 | 15 | 2.94 | 3.27 | – 19 | – 6 |
| IEA-8 | 8 | 14 | 2.89 | 3.16 | – 17 | – 6 |

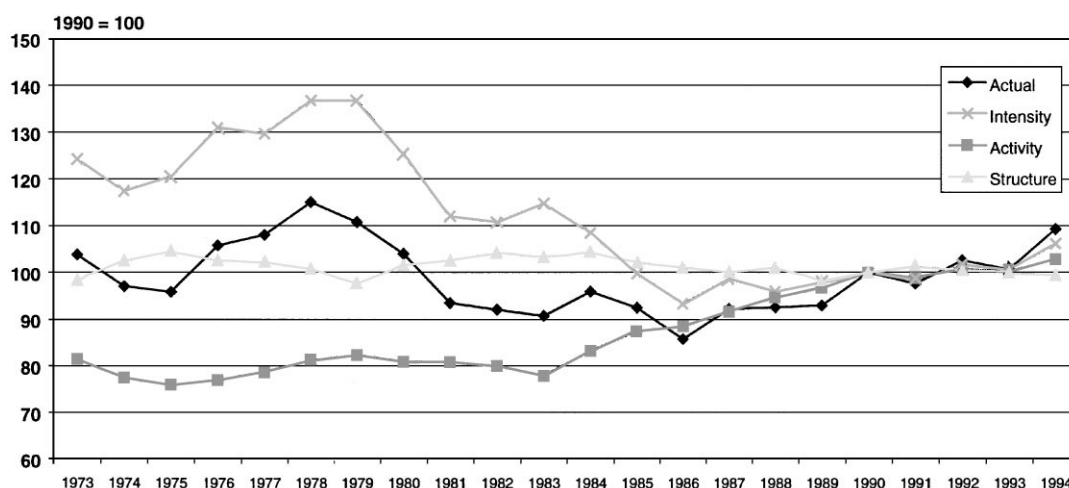


Fig. 7. IEA-8 delivered energy decomposition effects 1973–1994.

suggests that electrification often brings important increases in manufacturing productivity of all factors, hence this increase is not “bad” per se. However, it is not clear that electrification in sectors other than manufacturing delivers such countervailing benefits.

6.1.1. AWD decomposition of other industries delivered energy use

To further examine trends in energy consumption over time we use the AWD decomposition method to determine the respective roles that economic activity, sectoral structure, and energy intensity play in delivered energy consumption. This decomposition allows us to examine the effects of changes in energy intensity while controlling for shifts away from (or to) more energy-intensive industries within the sector. Fig. 7 depicts the sum of the decomposition results of the IEA-8 countries indexed to 1990. In other words, the hypothetical 1973 emissions due to the intensity effect (emissions at 1973 intensities but 1990 activities and structures) were summed across all countries and divided by the sum of the actual

1990 emissions. This procedure was then repeated for each effect for all years in the study period.

The intensity effect shows a decline in 1974 in the wake of the oil price shock. However, the increasing intensity effect from 1974 to 1978 is less predictable. This increase was propelled mostly by a 34% increase in energy intensity in agriculture. Increases of this magnitude occurred in Finland, Japan, the US, and Sweden. Economic activity in this sector remained quite stable to 1983. The increase in activity beginning in 1984 is largely the result of the rapid recovery of the construction industry in the last half of the 1980s, particularly in Japan where the value added increased 50% from 1984 to 1990. IEA-8 construction value added grew at 3.8% per year over this period but has leveled off since 1990. The structure of other industries has been remarkably consistent over the study period. The modest fluctuations in structure have primarily been a function of cycles in the construction industry. Although actual energy use remained below 1973 consumption from 1981 to 1991, both strong growth in agriculture and construction and increasing

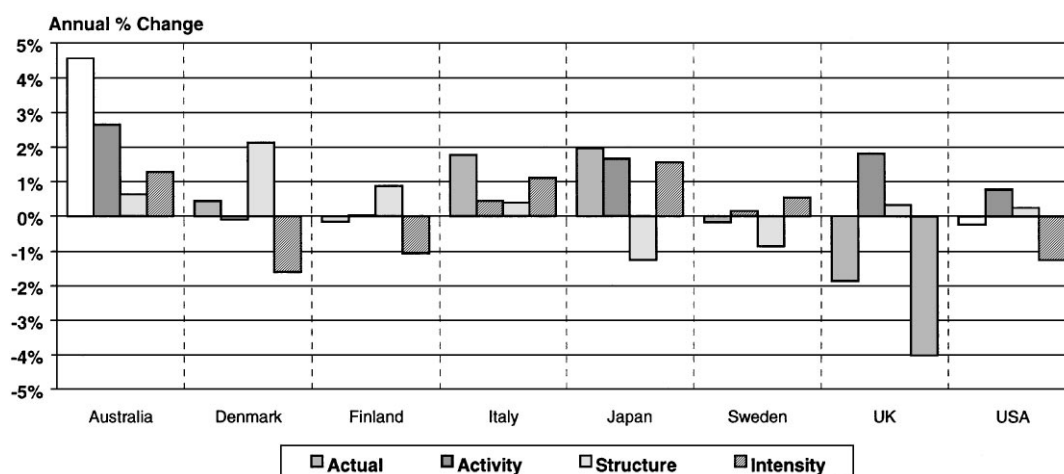


Fig. 8. IEA-8 other industries energy decomposition effects 1973–1994.

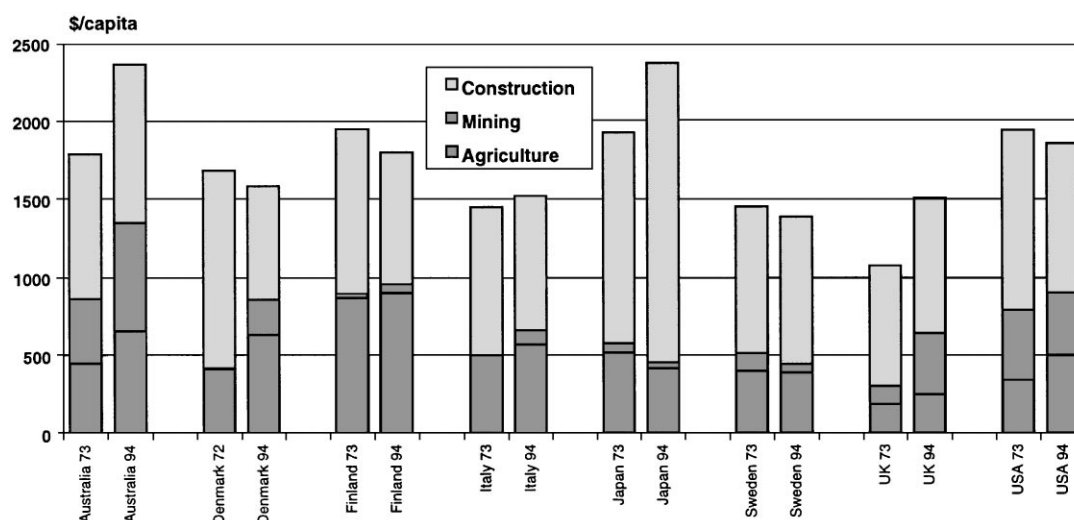


Fig. 9. Other industries' GDP per capita by subsector.

energy intensity in the US mining industry during 1994 sufficed to elevate IEA-8 energy use to slightly above the 1973 level.

Fig. 8 depicts the annual growth rates of these effects in each country resulting from the decomposition of energy use. The chart shows that the sample countries are evenly split in regard to whether energy use has increased over the study period. The UK, where substantial energy intensity reductions were accomplished in all three of the other industries, has experienced the greatest reductions in total energy use and aggregate energy intensity. The UK industries' strides in reducing energy intensity were critical in offsetting the upward pressure on emissions from output growth. To some extent the drop in energy intensity is due to a shift in mining activity from coal to oil and gas. Surprisingly, no consistent downward trend in energy intensity emerges among the IEA-8 countries as a whole.

Fig. 8 also shows that structural changes in the sector tended to favor more energy-intensive industries. Despite the construction boom of the late 1980s, construction output grew the least over the entire period causing a slight decline in construction's share of value added. Upward pressure on energy use from this effect was highest in Denmark, but declining energy intensity helped offset this. The increasing aggregate energy intensities cited above for Australia and Italy were exacerbated by structural shifts, whereas structural changes helped to mitigate Japan's increasing subsectoral energy intensities. Japan and Sweden were the only IEA-8 countries that experienced structural shifts toward less energy intensity.

Changing output trends are displayed in greater detail in Fig. 9. The value added figures have been scaled to population to facilitate comparability among the IEA-8 countries. Denmark, with the greatest degree of

structural change, experienced the greatest decline in construction value added and was the only country where the value added by construction fell while mining and agriculture both grew significantly. As noted above, the change in the relative shares of Japan's other industries was just the contrary. In six countries the real output per capita of construction declined, which is largely responsible for the structural trend toward greater energy consumption. Sweden's declining structure effect results from diminished output in mining, which is by far the most energy intensive of its other industries.

6.2. Carbon emissions results in other industries

In 1994 emissions from IEA-8 countries' other industries totaled 117 MtC, up from 106 MtC in 1973, an annual increase of 0.5%. Changes in carbon emissions varied widely across the sample countries. Commensurate with economic activity in the sector most countries experienced slow growth or stagnation in emissions. Only Australia, with an increase of 134%, exhibited an unusually large increase in emissions. Sweden and the UK had absolute decreases in emissions while US emissions grew only slightly over the study period.

The IEA-8 countries' aggregate other industries carbon intensities fall into two distinct clusters, as shown in Fig. 10. The 1994 carbon intensities of Australia, the US, and Denmark lie between approximately 210 and 150 gC/\$ value added. The remaining countries all have carbon intensities less than 100 gC/\$.

In contrast to the manufacturing industries, which demonstrated significant declines in carbon intensity in all IEA-8 countries, carbon intensity for other industries showed both increases and decreases among the IEA-8. Total IEA-8 carbon intensity declined only 12% over the study period. Increasing carbon intensity in Australia's

mining industry resulted in Australia surpassing the US as having the most carbon intensive other industries sector. The most significant decreases in carbon intensity occurred in Sweden and the UK. Trends in the subsectoral carbon intensity in the IEA-8 roughly parallel those for energy intensity. Agriculture and mining carbon intensities both decreased by about one-fourth, while carbon intensity in construction changed very little.

6.2.1. Decomposition of carbon emissions trends in other industries

Total sectoral emissions may be thought of as the product of output and aggregate sectoral carbon intensity. According to our decomposition method, changes in activity level have the same effect on sectoral carbon emissions as they do on sectoral energy use. Therefore, we present in this section only a decomposition of aggregate carbon intensity, which is summarized in Fig. 11. The bars represent the average annual rate of growth of the aggregate carbon intensity and the rates that would be attributable to the underlying decomposition factors: structure, subsectoral energy intensity, fuel mix, and utility mix.

Structure and energy intensity effects for carbon intensity will usually closely match the energy decomposition results for these terms. The effects are not necessarily identical, however, due to differences among the industries in the ratio of the carbon released per unit of energy consumed, which varies according to the fuel mix used by each industry. For example, a decrease in energy intensity by an industry using a high-carbon fuel mix will have a greater effect on aggregate carbon intensity than an identical energy intensity decrease by a similarly sized industry using a lower carbon fuel mix, even though the effect on energy intensity is the same. A comparison of the energy decomposition results and the carbon results

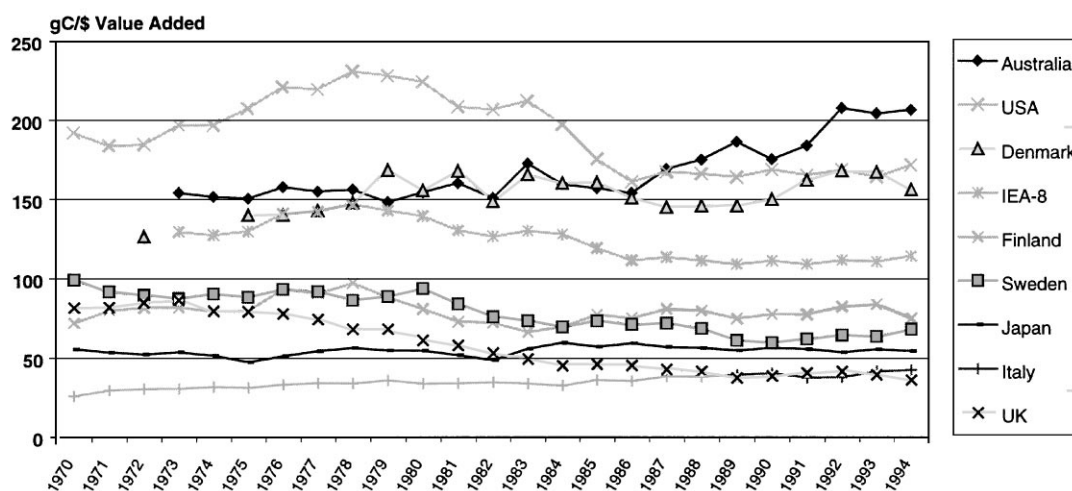


Fig. 10. Carbon intensity of other industries.

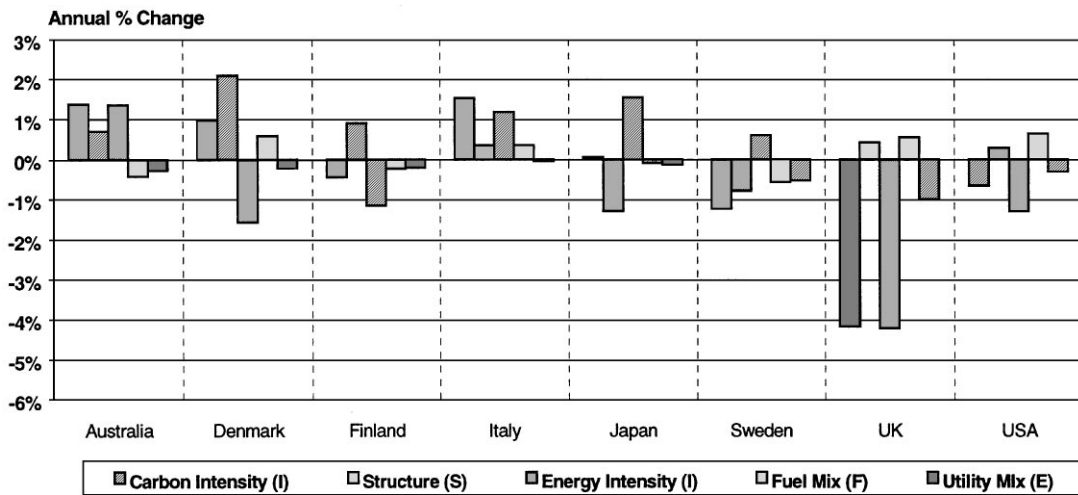


Fig. 11. Components of changes in aggregate carbon intensity, 1973–1994.

yielded no significant discrepancies in either decomposition term. Thus, the same findings regarding structure and energy intensity discussed in the “Energy Consumption Trends” section above apply to aggregate carbon intensity as well. This means that by and large energy-saving efforts in these sectors will save carbon. Fuel switching away from coal or in some cases oil can save additional carbon.

Among the IEA-8, changes in fuel mix had varied effects. In Denmark, the US, the UK, and Italy, fuel switching increased emissions from 8 to 19%. The other four countries experienced modest decreases in emissions from this effect. On average, fuel-share contributions to carbon emissions changed very little in the IEA-8 from 1973 to 1994. Oil’s share accounted for 46% in 1973 and 45% in 1994, while coal accounted for 1 and 2% of emissions, respectively. A trend toward greater electrification accompanied a commensurate decline in the use of natural gas over the study period, principally between 1976 and 1986. However, natural gas consumption began to rebound after 1986, increasing at an average annual rate of 6.6% to 1994. The mining industries of Australia and the US were the main drivers of this growth in natural gas consumption. Natural gas played a significant part in restraining emissions from both countries. If energy demand met by natural gas in their other industries had been met by oil, emissions from Australia and the US would have been 8 and 12% higher, respectively.¹³ Fig. 12 provides an overview of the changes in emissions fuel shares for all IEA-8 countries.

In most of the IEA-8 countries, emissions from electricity use constitute a considerable share of total emissions. This ranges from a high of 41% for Australia to

a low of just 2% in Sweden. Sweden actually had the highest percentage of electricity in its fuel mix, but Sweden also generates more of its electricity from nuclear and hydropower than any other IEA-8 country, resulting in the lowest carbon coefficient for electricity. Electricity consumption more than doubled in Australia, Denmark, and Italy and increased more than 80% in the US. Among the other industries electrification was greatest in the mining industry in which the electricity share grew from 9 to 16%. Electricity as a share of energy use in this sector increased in every country except for Australia and Japan.

As described above, the relative increase in electricity consumption reflects similar trends in the services, manufacturing, and residential sectors and has profound effects on carbon emissions. The decline in natural gas use that accompanied the growth in electricity use would have had a stronger effect on emissions had there not also been a concurrent trend toward decarbonization in the utility mix. From the decompositions presented in Fig. 11, evidence of these countervailing trends manifest most clearly in the US and the UK results. The IEA-8 average carbon coefficient decreased 18% from 1973 to 1994. Fig. 11 shows that the utility mix effect helped to push down emissions in each of the IEA-8 countries. In the UK, where the utility mix effect was most pronounced, nuclear power input to the generation mix more than doubled while natural gas increased more than eight-fold. Inputs from oil and coal declined in both countries. In Sweden the carbon coefficient is sufficiently low enough that electrification actually helps to push emissions down from the fuel mix effect.

6.2.2. Other industries mine-yours analysis

In the wake of the Kyoto Protocol, one benchmark of fairness in setting carbon reduction targets that has been proposed, particularly by developing nations, is to set

¹³ These figures do not take into account differences in combustion efficiencies for various fuels and end-uses.

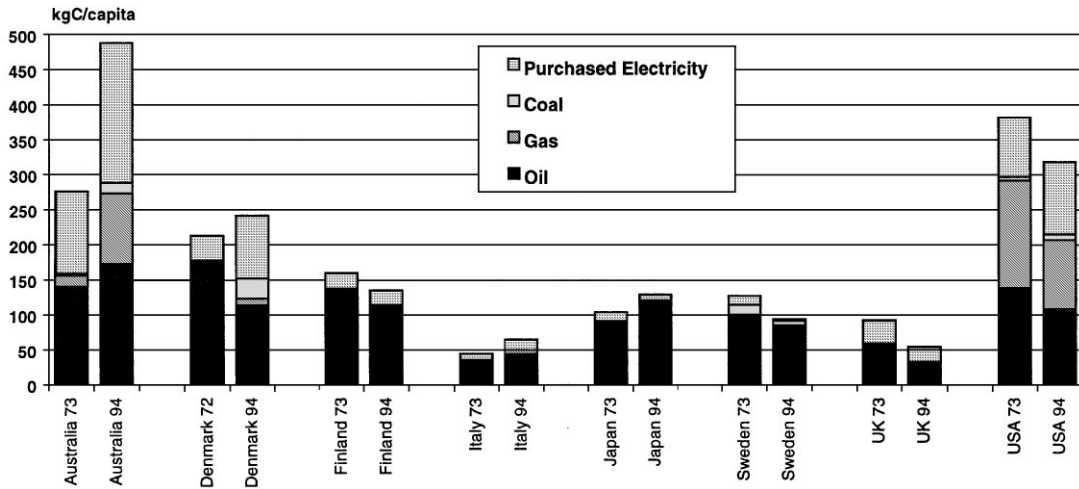


Fig. 12. Carbon emissions from other industries by energy source.

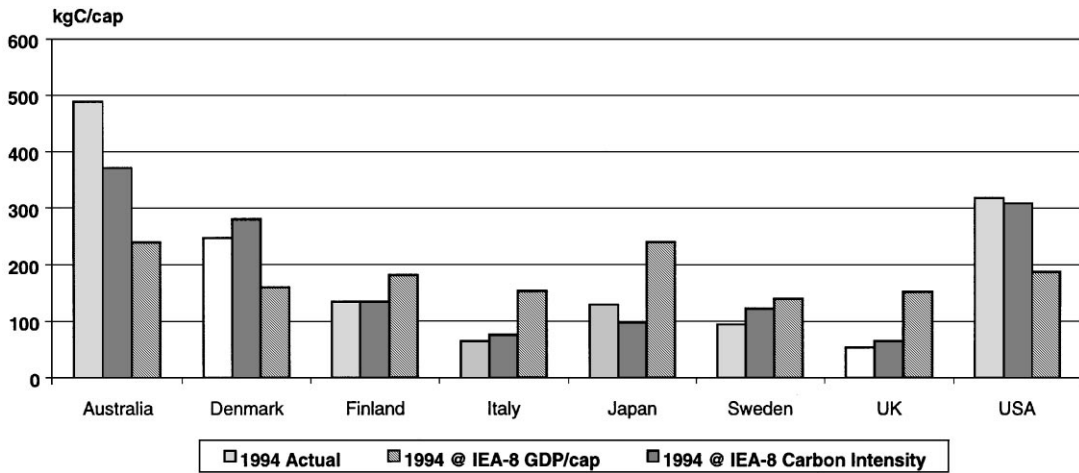


Fig. 13. Other industries carbon emissions per capita and at average sectoral GDP and carbon intensity.

future expectations based on emissions per capita (see for example Srinivasan, 1992). But even among the developed countries, enormous differences in emissions per capita exist (IES, 2000; IEA, 1997). To develop effective carbon restraint policies, it will be critical to understand why such large variations exist. At a very basic level of decomposition carbon emissions per capita may be thought of as the product of carbon intensity (in terms of C/\$) and GDP (in \$/capita). It is important to distinguish between the two (output and the carbon intensity factor) because policy makers are not likely to reduce carbon emissions by restraining economic output.

Fig. 13 depicts the results of a basic mine–yours analysis that attributes the differences in other industries per capita carbon emissions to carbon intensity and GDP/capita. It is evident in Fig. 13 that for other industries, the differences in carbon intensity are more important than differences in output in determining the

variation in emissions per capita. The average absolute deviation from actual emissions for the GDP/capita substitution is only 17%. However, as previously mentioned, the IEA-8 countries fall into two distinct clusters according to other industries aggregate carbon intensities, and this disparity results in an average absolute deviation of 77% for the carbon intensity substitution.

Our mine–yours analysis of the aggregate carbon intensities helps illuminate some of the underlying causes of the large differences in aggregate carbon intensity. Substitution of average subsectoral energy intensities has the most overall effect. The average deviation from actual carbon intensity resulting from this substitution is 72%. Substitution of this term more than doubles emissions in Italy and nearly triples them in the UK. Carbon intensity from this substitution falls most for the US. This mine–yours comparison shows that while other effects are significant, variations in energy intensities among the

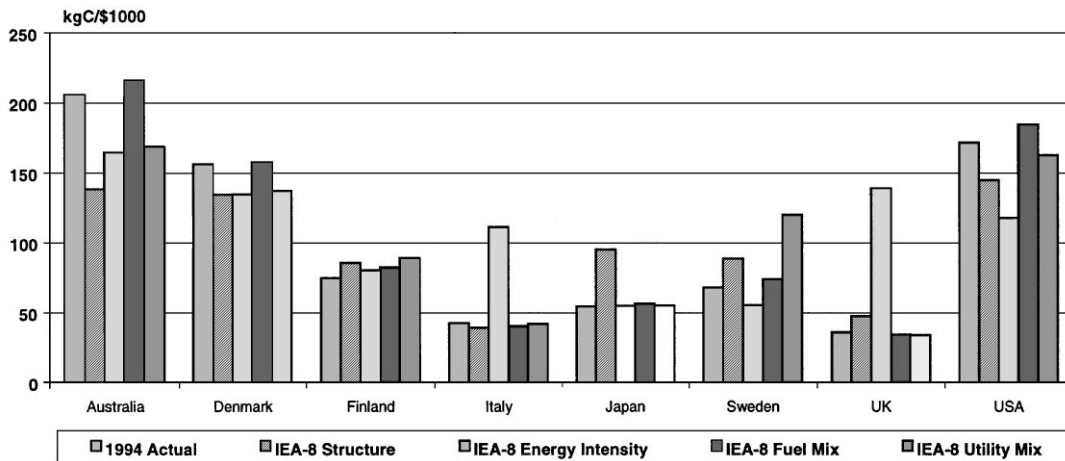


Fig. 14. Mine-yours analysis for 1994 carbon intensity.

IEA-8 still account for the greatest part of the differences in carbon intensity, and implicitly carbon emissions from other industries (Fig. 14).

Of the four terms analyzed, fuel mix is the least important. It would increase total emissions by about 10% in Sweden and Finland and affect emissions considerably less in the other countries. Substitutions of utility mix and structure have roughly equal impacts on carbon intensity. The only country for which utility mix has a large impact is Sweden, whose emissions would increase 76%.

The structure effect changes actual carbon intensity by 30% or more in four of the countries. Japan, whose construction industry accounts for the largest share of GDP among the IEA-8, benefits most from having a low carbon intensive structure — at IEA-8 structure its carbon intensity would increase by 75%. Australia, where mining accounts for the largest share of GDP, not surprisingly has the most carbon intensive structure. If Australia had the average IEA-8 structure, aggregate carbon intensity would drop by one-third. Structure substitution yields the next largest reduction for the US.

7. Comparison of other industries and refining to manufacturing

If other industries and refining were included in industrial energy and output statistics¹⁴ 1994 IEA-8 manufacturing energy use and carbon emissions would increase

approximately 40%. The addition to output is even greater, however, implying that other industries and refining together are less energy intensive than manufacturing. Since refining is very energy intensive, however, this means that other industries are less energy intensive than manufacturing, with a few important exceptions we noted, namely, mining in some countries.

Table 4 provides the percent changes from actual manufacturing indicators for 1973 and 1994 for the IEA-8 when refining and other industries are included. These industries together represent more than 40% of manufacturing value added and more than 20% of manufacturing carbon emissions in every country. Obviously, policies aimed at improving energy efficiency or abating carbon emissions from industry cannot afford to overlook such important contributors to national emissions.

Refining in many countries is the most energy-intensive industry, but the value added from other industries dwarfs that of refining (IEA-8 refining value added was less than 3% of other industries in 1994). Since together these industries contribute proportionally more to value than energy consumption, the overall effect is to bring energy and carbon intensities down. This is not true for the US and Sweden where refining represents a relatively larger share of output in manufacturing.

As the differences in the AWD decompositions of industry with and without refining indicated, the inclusion of refining does not significantly change the trends in the decomposition factors. However, including both refining and other industries does significantly slow the rate of decline in aggregate energy and carbon intensities for the IEA-8 because intensities have fallen less sharply in these industries than in other branches of manufacturing. Despite the slower growth of this sector compared to manufacturing the carbon emissions shares have grown or remained steady in most countries due to the lack of progress in reducing carbon intensity in this sector. Thus,

¹⁴ While the IEA does not include refining and energy resource extraction in the industry classification, many IEA member countries do. The US places agriculture by default in this classification when presenting the most aggregated sectoral breakdowns, e.g., transport, residential/commercial, and industry.

Table 4
Percent changes in energy, emissions, and output indicators for manufacturing from including other industries and refining

| Country | Energy 1973 (%) | Energy 1994 (%) | Carbon emissions 1973 (%) | Carbon emissions 1994 (%) | Output 1973 (%) | Output 1994 (%) | Energy intensity 1973 (%) | Energy intensity 1994 (%) | Carbon intensity 1973 (%) | Carbon intensity 1994 |
|--------------------|-----------------------|-----------------------|---------------------------------|---------------------------------|-----------------------|-----------------------|---------------------------------|---------------------------------|---------------------------------|-----------------------------|
| Australia | 31 | 46 | 30 | 42 | 83 | 105 | – 28 | – 28 | – 29 | – 30 |
| Denmark | 39 | 70 | 36 | 57 | 72 | 59 | – 19 | 7 | – 21 | – 1 |
| Finland | 26 | 16 | 25 | 21 | 96 | 56 | – 36 | – 25 | – 36 | – 22 |
| Italy | 18 | 24 | 17 | 22 | 71 | 43 | – 31 | – 13 | – 32 | – 14 |
| Japan | 19 | 28 | 16 | 23 | 67 | 49 | – 29 | – 15 | – 31 | – 17 |
| Sweden | 13 | 21 | 18 | 51 | 54 | 43 | – 27 | – 16 | – 23 | 6 |
| UK | 21 | 29 | 19 | 25 | 37 | 51 | – 12 | – 14 | – 14 | – 17 |
| USA | 55 | 51 | 47 | 51 | 61 | 46 | – 4 | 3 | – 9 | 3 |
| IEA-8 ^a | 40 | 42 | 34 | 40 | 61 | 48 | – 13 | – 2 | – 17 | – 5 |

^a These figures represent weighted averages.

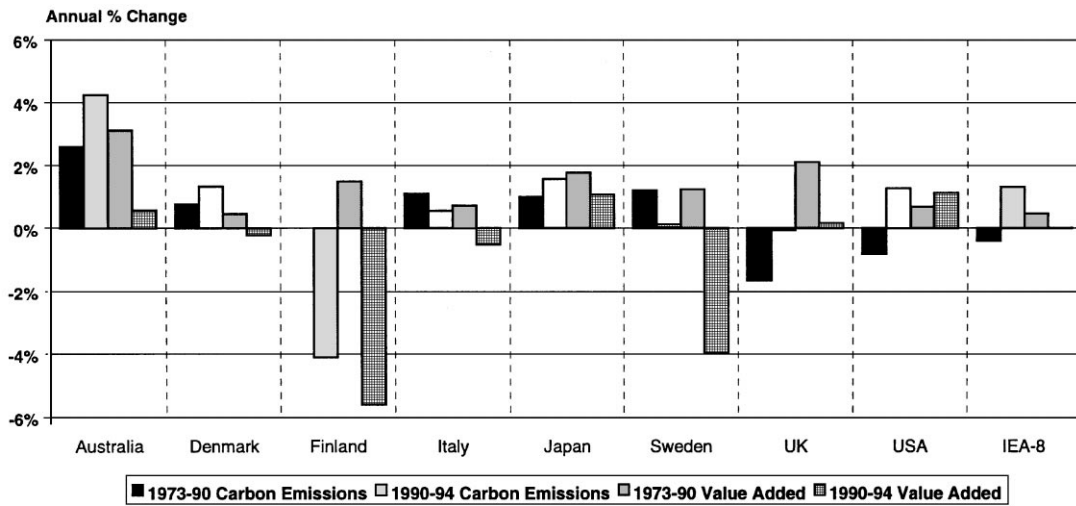


Fig. 15. Trends in other industries and refining carbon emissions and value added, 73–90 vs. 90–94.

while the share of other industries and refining in manufacturing value-added has fallen, the share of carbon emissions has actually increased.

There is one additional effect we have not been able to study. There are certainly hidden structural changes within these industries. Changes in the mix of mining, agricultural, and even construction outputs likely have had an impact on energy use, but the magnitude and sign cannot be determined with available data. Within refining, efforts to save energy have been notable but offset to some extent by changes in the refining mix towards more gasoline (see Fig. 5), which requires more energy for refining than heavier products. While we believe we have captured most of the important structural and intensity changes in the sectors we have analyzed, we know there is somewhat more to the story that is beyond the scope of our investigation.

8. Comparison of pre and post 1990 trends

The agreement reached in the Kyoto Protocol set 1990 as the base year to which carbon emissions reduction targets would be set. In this section we compare trends in other industries and refining before and after 1990 to get a sense of how the IEA-8 have done in the early 1990s in reducing carbon emissions from these industries. Fig. 15 provides a broad overview of trends in other industries emissions and economic activity. The rate of emissions has increased in five countries. The increase in the rate of emissions in the IEA-8 is attributable mostly to the growth in emissions in the US and Australia. The rate of growth in value added from other industries has declined in every country but the US. A surge in US agricultural value added in the early 1990s was largely responsible for the small increase in growth for the sector. Declining

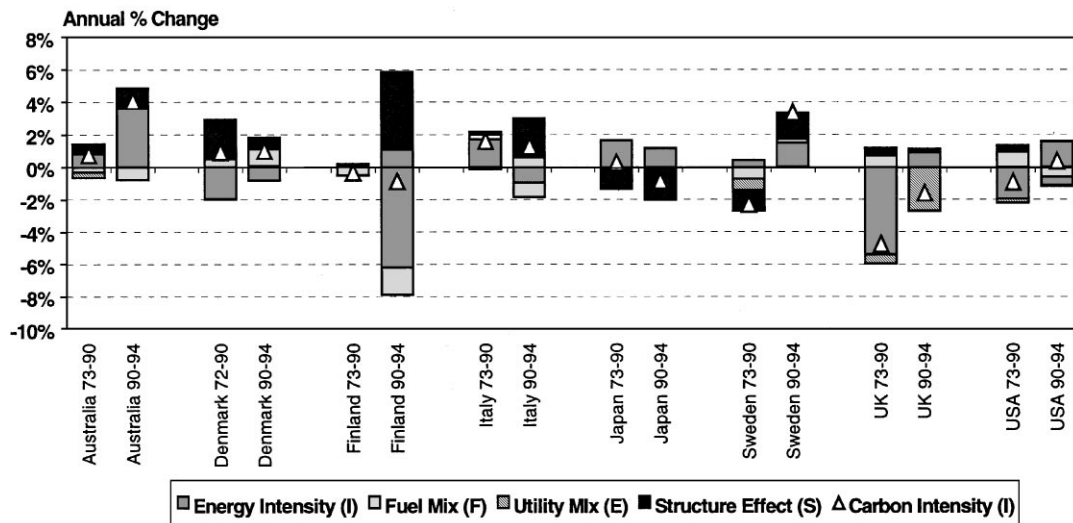


Fig. 16. Other industries aggregate carbon intensity decompositions, 73–90 vs. 90–94.

levels of output played a significant role in bringing down the rate of emissions in several countries, particularly in Finland and Sweden. In all countries but Japan and the US, construction, the least carbon-intensive industry, suffered the largest economic downturn. This helps explain the seemingly contradictory trends for the IEA-8 that carbon emissions grew from 1990 to 1994 while aggregate value added stagnated.

We provide a more detailed look at the change in growth rates of the decomposition terms in Fig. 16. The triangle marker represents the rate of change in aggregate carbon intensity, and shadings on the bars illustrate the rates of change attributable to each of the decomposition factors. The rate of change of aggregate carbon intensity has increased markedly in the US, the UK, Australia, and Sweden. The terms that have had the largest effect on changing trends in other industries are structure and energy intensity. The relative decline of the construction industry since 1990 has led to an increase in carbon intensity due to structural change for most countries. In Finland, for example, the construction industry declined from 59% of sectoral value added in 1990 to 47% in 1994. In Sweden construction fell from being the most rapidly growing of the other industries to the most rapidly declining.

Energy intensity has changed significantly in most of these countries since 1990. Unfortunately, recession in some countries clouds the interpretation of the results, since intensities often increase in mild recessions due to lower capacity utilization. Indeed energy intensity has increased in five of the IEA-8 countries. It is difficult to determine why energy intensity would have increased in several countries following 1990. Since we do not have data disaggregated down to individual mining or agricultural products, these changes in energy intensity may be due to structural shifts at the branch level. In all of the

countries where energy intensity increased, intensity changes in agriculture and mining played the biggest role in pushing up carbon intensity, with the exception of Sweden, whose mining intensity declined and construction intensity increased. As with petroleum prices, other commodity prices also began to fall steeply by the mid-1980s (World Bank, 1999). This may have helped to drive up energy intensities in mining and agriculture by depressing value added arising in these sectors.

Shifts in fuel mix have had relatively little effect in altering the rate of change in other industries carbon intensity. In Sweden, the US, and Finland, which have all reduced carbon intensity from fuel switching since 1990, gas use has risen while electricity consumption has fallen. Since electricity comprises a relatively small share of other industries' energy use, changes in utility fuel consumption have also played only a small role in altering the aggregate trend since 1990.

Overall the trends in carbon intensity between 1990 and 1994 do not show a significant decarbonization consistent with the long-term goal of restraint in carbon emissions from these sectors. As data become available from the late 1990s, by which time most economies had recovered from the recession of the early 1990s, we will more clearly be able to understand how well decarbonization is proceeding.

9. Discussion

As noted above, the continuing fall in commodity prices may be partly masking a greater increase in physical production from agriculture, mining, and refining than the value added numbers reveal, which would help to explain the increasing economic energy intensities. However, the product mix from these industries is quite

diverse and reliable energy data disaggregated to individual agricultural and mining products do not exist. Although value added may be a less accurate indicator of activity for these industries than for manufacturing, it is necessary to use an economic indicator due both to the limitations of the energy data and the need for comparability across several products and between different industries.

We would also like to point out that while other industries and refining account for a relatively small share of national GDP in the IEA-8, the implications of this study may be much more profound for developing countries where these industries constitute a considerably larger share of GDP. Other industries alone contributed approximately 37% of 1994 GDP in the Philippines, 34% in Indonesia, and 36% in India (Asian Development Bank, 1996). Energy data for these industries have been difficult to standardize and verify for many IEA member countries. In developing nations where other industries are likely to be responsible for a much larger share of emissions, it is imperative to develop reliable data collection systems to account for their energy demand.

10. Conclusions

We have five basic findings. First, “other industries” tends to be a minor consumer of energy in many countries, but in some, particularly Denmark, the US, and Australia, mining or agriculture can be a major sector too large to be overlooked. Second, refining is an extremely energy intensive industry which despite a relatively low share of value added consumes as much as 20% of final energy use in manufacturing. Third, as a result of a slower decline in the carbon intensity of these industries vis-à-vis the manufacturing industries, their share of industrial emissions has been rising. Fourth, for other industries variation in per capita output plays a relatively small role in differentiating per capita carbon emissions compared to the impact of subsectoral energy intensities. Finally, including this energy in CO₂ calculations has little impact on overall trends, but does change the magnitude of emissions in most countries significantly. Clearly, these industries provide important opportunities for searching for carbon emissions reductions.

For most countries other industries and refining represent energy use and carbon emissions too important to totals to be ignored by GHG restraint policies. Unfortunately, for some IEA countries key data for these industries are either missing or questionable. Therefore, we do not know with any certainty how trends in carbon emissions may be changing for many IEA member countries. Although the omission of these industries does not seem to significantly alter energy and emissions trends at the national level, they still represent 6–14% of total national

emissions among the IEA-8 countries. We cannot afford to “lose” emission shares of this magnitude through inadequate accounting. For some countries the share of these industries in total national energy use and carbon emissions has grown significantly.

Structural changes in other industries increased emissions for some countries although for the IEA-8 as a whole structural change had little effect. Denmark experienced the largest impact from this effect due to the growth of both agriculture and mining accompanied by declining construction output. In sharp contrast to the universal declines in manufacturing energy intensities in the IEA-8, energy intensity changes had a mixed effect for refining and other industries. Refining energy intensity increased in three countries, and other industries aggregate energy intensity (controlling for structural changes) increased in four countries.

Placing these industries in the industrial classification in national accounts will affect the calculation of aggregate energy and carbon intensity indicators. When included in national calculations for industrial energy use and emissions, they reduce “industry” energy intensities by an average of 13% among the IEA-8 countries. However, including other industries and refining would also tend to slow the rate of decline in aggregate industrial energy and carbon intensity, because energy intensity in these industries has been declining at a substantially slower rate than it has for manufacturing branches of industry.

As in other sectors there has been a trend toward greater electrification in other industries and refining, which has significant implications for total primary energy use and carbon emissions. IEA-8 other industries primary energy use and carbon emissions in 1994 were 14 and 9% higher, respectively, than they would have been at 1973 fuel shares.¹⁵ Changes in primary energy intensities are even less encouraging in other industries than the relatively modest decreases in delivered energy intensities. IEA-8 other industries delivered intensity decreased 17% from 1973 to 1994 while primary intensity decreased only 6%. As in the other non-transport sectors, the trend toward electrification provides some cause for alarm for its effect on total energy use and carbon emissions.

IEA-8 carbon emissions from refining and other industries have risen faster in the 1990s compared to the period 1973–1990. This trend is all the more disturbing because this has happened despite a sharp fall in value added in many countries and sectors. These seemingly contradictory trends are explained by the following factors: (1) output growth in Australia’s mining industry, which is the second-most carbon intensive in the IEA-8; (2)

¹⁵ Calculated using 1994 primary and carbon coefficients for electricity.

increasing energy intensities in the mining industries of both Australia and the US; and (3) increasing output and/or energy intensities in the refining industries of several IEA-8 countries.

Acknowledgements

Scott Murtishaw thanks British Petroleum and Shell International Petroleum Corp for support to the Goldman School of Public Policy, University of California Berkeley, for this work. Marta Khrushch acknowledges the hospitality of the IEA where some of this work was carried out. The IEA acknowledges the support of Denmark, the Netherlands, Australia, New Zealand, and Canada, whose voluntary contributions contributed to this analysis. Opinions expressed here are those of the authors and not their institutions or supporting authorities.

Appendix A. Index decomposition method

We attribute changes in manufacturing energy consumption to changes in the structure of output and changes in subsectoral energy intensity as follows

$$(1 + \Delta I_{tot}) = (1 + \Delta I_{struc})(1 + \Delta I_{int})(1 + D), \quad (A.1)$$

where D is the unexplained residual or approximation error of the difference between the sum of the three terms on the right-hand side and the total change in aggregate energy intensity. As indicated in previous work, this decomposition, which is expressed in a multiplicative form, may also be expressed in an additive form (Ang, 1994).

All decomposition methods in current use may be viewed as a member of a parametric family of indices (Ang, 1994), having either a continuous or discrete specification as follows

Parametric Divisia Method 1 (continuous)

$$(1 + \Delta I_{struc})_{0,T} = \exp \left\{ \sum_j \left[\frac{E_{j,0}}{E_0} + \beta_j \left(\frac{E_{j,T}}{E_T} - \frac{E_{j,0}}{E_0} \right) \right] \ln \left(\frac{S_{j,T}}{S_{j,0}} \right) \right\}, \quad (A.2)$$

$$(1 + \Delta I_{int})_{0,T} = \exp \left\{ \sum_j \left[\frac{E_{j,0}}{E_0} + \gamma_j \left(\frac{E_{j,T}}{E_T} - \frac{E_{j,0}}{E_0} \right) \right] \ln \left(\frac{I_{j,T}}{I_{j,0}} \right) \right\}. \quad (A.3)$$

Parametric Divisia Method 2 (discrete)

$$(1 + \Delta I_{struc})_{0,T} = \exp \left\{ \sum_j \left[\frac{I_{j,0}}{I_0} + \beta_j \left(\frac{I_{j,T}}{I_T} - \frac{I_{j,0}}{I_0} \right) \right] (S_{j,T} - S_{j,0}) \right\}, \quad (A.4)$$

$$(1 + \Delta I_{int})_{0,T} = \exp \left\{ \sum_j \left[\frac{S_{j,0}}{I_0} + \gamma_j \left(\frac{S_{j,T}}{I_T} - \frac{S_{j,0}}{I_0} \right) \right] (I_{j,T} - I_{j,0}) \right\}, \quad (A.5)$$

where for both methods, the underlying conditions are $0 \leq \beta_j, \gamma_j \leq 1$, and where $j = 1, 2, \dots, N$ industrial groups and T refers to a point of time greater than the base year.

Based on previous work (Greening *et al.*, 1996), we use the modified specification of the AWD Index method to attribute changes in aggregate energy intensity. In the modified or rolling base year specification, the weights change from year to year as output and energy consumption changes. The weights are determined by equating the continuous and parametric methods and solving for the specified parameters as follows:

It can be demonstrated that for these parameters the underlying condition $0 \leq \beta_j, \gamma_j \leq 1$ is met. The weightings may be applied to either Parametric Method 1 or 2 with the same result.

References

- Ang, B.W., 1994. Decomposition of industrial energy consumption. *Energy Economics* 16(3), 163–174.
- Asian Development Bank (ADB), 1996. *Key Indicators of Developing Asian and Pacific Countries*. Oxford University Press, Oxford.
- Greening, L., Davis, W.B., Schipper, L.J., 1996. Decomposition of aggregate carbon intensity for the manufacturing sector: comparison of declining trends from ten OECD countries for the period 1971 to 1991. *Energy Economics* 18(1), 43–65.
- Greening, L., Davis, W.B., Schipper, L.J., Khrushch, M., 1997. Comparison of six decomposition methods: application to aggregate energy intensity for manufacturing in ten OECD countries. *Energy Economics* 19(3), 375–390.
- IEA (International Energy Agency), 1994. *Energy Prices and Taxes: Third Quarter 1994*. IEA/OECD, Paris.
- IEA, 1997. *CO₂ Emissions from Fuel Combustion*. IEA/OECD, Paris.
- IEA, 1998. *Energy Statistics and Balances of OECD Countries* (diskette service). IEA/OECD, Paris.
- IES (International Energy Studies), 2000. *IES database of official national energy and economic statistics*. Lawrence Berkeley National Laboratory, Berkeley, CA.
- IPCC (Intergovernmental Panel on Climate Change), 1996. *Greenhouse Gas Inventory Reference Manual*. IPCC Guidelines for National Greenhouse Gas Inventories. IPCC, Geneva.
- Liu, X.Q., Ang, B.W., Ong, H.L., 1992. The application of the divisia index to the decomposition of changes in industrial energy consumption. *Energy Journal* 13(4), 161–171.
- Schipper, L.J., Price, L., 1994. Efficient energy use and well being: the Swedish example after 20 years. *Natural Resources Forum* 18(2), 125–142.
- Schipper, L., Murtishaw, S., Unander, F., 2000. One man's carbon is another man's bread: further understanding differences in the structure of carbon emissions. In: *Proceedings of the 23rd IAAE International Conference*, 7–10 June 2000, Sydney.
- Schurr, S.H., 1982. Energy efficiency and productive efficiency: some thoughts based on american experience. *The Energy Journal* 3(3), 3–14.

- Srinivasan, T.P., 1992. Basic approach of developing countries to the negotiations for a climate change convention. In: Frame, B., Medury, Y., Joshi, Y. (Eds.), *Global Climate Change: Science, Impacts, and Responses*. Tata Energy Research Institute, New Delhi (Proceedings of the Indo-British Symposium on Climate Change, 15–17 Jan. 1992, New Delhi], 267 pp.
- Unander, F., Karbuz, S., Schipper, L., Khrushch, M., Ting, M., 2000. Manufacturing energy use in OECD countries: decomposition of long-term trends. *Energy Policy* 27(13), 769–778.
- World Bank, 1999. World Development Indicators. http://www.worldbank.org/data/wdi/pdfs/tab6_4.pdf accessed November, 1999.
- Worrell, E., Cuelenaere, R.F.A., Blok, K., Turkenburg, W.C., 1994. Energy consumption by industrial processes in the European union. *Energy* 19(11), 1113–1129.
- Worrell, E., Price, L., Martin, N., Farla, J., Schaeffer, R., 1997. Manufacturing intensity in the iron and steel industry: a comparison of physical and economic indicators. *Energy Policy* 25(7–9), 727–744.